

The Impact of Scale

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Today's Speaker

Linda Northrop is director of the Research, Technology, and Systems Solution Program at the Software Engineering Institute where she leads the work in architecture-centric engineering, software product lines, systems of systems, and ultra-large-scale systems.

She is coauthor of *Software Product Lines: Practices and Patterns*. She recently led a year long study including leaders in the software community to define technical and social challenges to the creation of ultra-large-scale systems that will evolve in the next generation. The group published the study report, *Ultra-Large-Scale Systems: The Software Challenge of the Future (ISBN 0-9786956-0-7)*.

Before joining the SEI, she was associated with both the United States Air Force Academy and the State University of New York as professor of computer science, and with both Eastman Kodak and IBM as a software engineer.



Polling Question 1

How did you hear about this webinar?

1. Email invitation from the SEI
2. SEI Website
3. Website with webinar calendar (ie www.webinar-directory.com)
4. Social Media site (LinkedIn, Twitter)
5. SEI Member Bulletin



Societal Problems

Climate change and the environment

Powering our civilization

Disease, epidemics, and health care

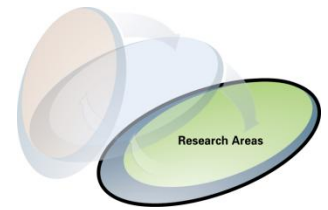
Livable megacities

Safety and security

Transportation



Trend Toward Increasing Scale-1



- Enormous web service and computing infrastructure
- Supply chain systems
- Software-based engineering systems



Trend Toward Increasing Scale - 2



Healthcare Infrastructure



Military Systems



Homeland Security



Networked Automobiles



Saving the Environment



Increasing Scale In Military Systems

Increasingly Complex Systems

- ultra-large, network-centric, real-time, cyber-physical-social systems
 - thousands of platforms, sensors, decision nodes, weapons, and warfighters
 - connected through heterogeneous wired and wireless networks

Goal: Information Superiority

- *Transient and enduring resource constraints and failures*
- *Continuous adaptation*
 - changes in mission requirements
 - changes in operating environments
 - changes in force structure
 - perpetual systems' evolution
 - addition of new systems
- *Sustainable - legally, technically, politically*



The Challenge



*The Honorable
Claude M. Bolton, Jr.*

“Our soldiers depend on software and will depend more on software in the future.

The Army’s success depends on software and the software industry.

We need better tools to meet future challenges, and neither industry nor government is working on how to do things light-years faster and cheaper.

How can future systems, which are likely to be a **billion lines of code**, be built reliably if we can’t even get today’s systems right?”

— Asst Sec Army Claude Bolton
August 16, 2005



Ultra-Large-Scale (ULS) Systems Study

Gather leading experts to study:

- characteristics of ULS systems
- challenges and breakthroughs required
- promising research and approaches

Intended outcomes:

- ULS System Research Agenda
- program proposal
- collaborative research network

About the Effort

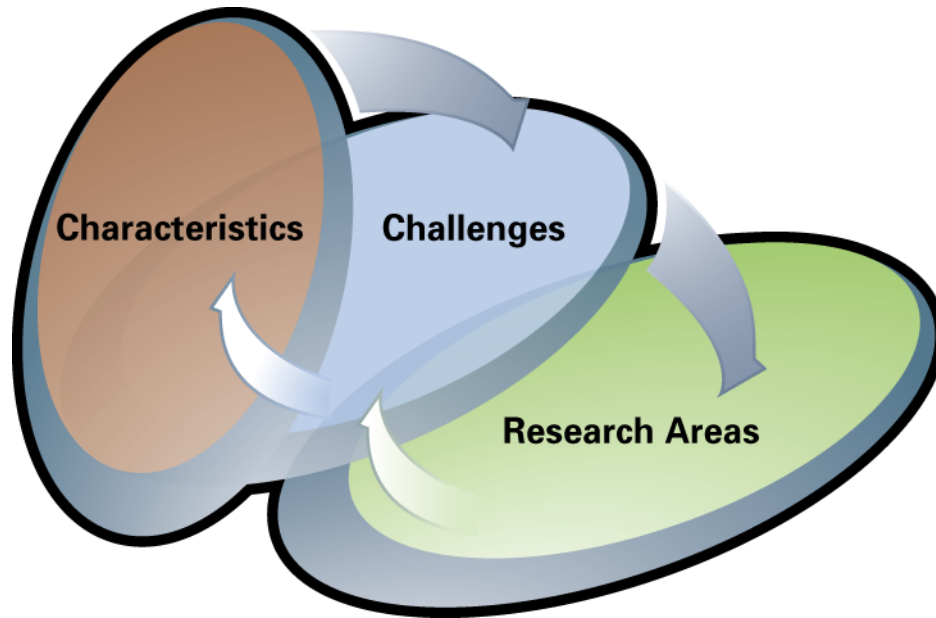
Funded by the Army (ASA ALT)

*Staffing: 9 member SEI team
13 member expert panel*

Duration: one year (04/05 -- 05/06)



ULS Systems Research Agenda



Describes

- the characteristics of ULS systems
- the associated challenges
- promising research areas and topics

Is based on a new perspective needed to address the problems associated with ultra-large-scale systems.



Polling Question 2

Prior to this webinar have you heard about this study?

- 1) Heard about it but haven't read the report.
- 2) Read the report.
- 3) Had not heard about it.



Instead: A Different Kind of Study

It presents an overall research agenda -- not just for new tools or a new software method or modest improvements in today's approaches.

It is based on the challenges associated with ultra-large scale.

It focuses on the future.

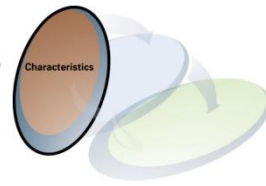
It involves an interdisciplinary base.

It takes a fresh perspective on the development, deployment, operation, and evolution of software-intensive systems.

Germes of these ideas are present today in small research pockets; these efforts are currently too small to have much impact on next-generation ULS systems.



What Is an Ultra-Large-Scale (ULS) System?



A ULS System has unprecedented scale in some of these dimensions:

- lines of code
- amount of data stored, accessed, manipulated, and refined
- number of connections and interdependencies
- number of hardware elements
- number of computational elements
- number of system purposes and user perception of these purposes
- number of routine processes, interactions, and “emergent behaviors”
- number of (overlapping) policy domains and enforceable mechanisms
- number of people involved in some way

ULS systems will be interdependent webs of software-intensive systems, people, policies, cultures, and economics.

ULS systems are systems of systems at internet scale.



ULS Systems and Systems of Systems

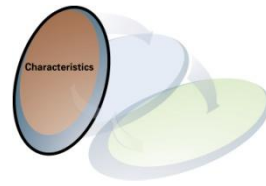
- Directed: the systems are integrated and built to fulfill specific purposes
- Acknowledged: has recognized objectives, a designated manager, and resources
- Collaborative: components voluntarily agree to fulfill central purposes
- Virtual: no central authority or centrally agreed purpose
...and beyond

ULS Systems

¹ Adapted from Maier, M. (1998); "Architecting Principles for Systems-of-Systems"; Systems Engineering, Vol. 1, No. 4 (pp 267-284).



Scale Changes Everything



Characteristics of ULS systems arise because of their scale.

- Decentralization
- Inherently conflicting, unknowable, and diverse requirements
- Continuous evolution and deployment
- Heterogeneous, inconsistent, and changing elements
- Erosion of the people/system boundary
- Normal failures
- New paradigms for acquisition and policy

These characteristics may appear in today's systems and systems of systems, but in ULS systems they dominate.

These characteristics undermine the assumptions that underlie today's software engineering approaches.



Polling Question 3

Do you see these characteristics in systems you are working on?

1. Decentralization
2. Inherently conflicting, unknowable, and diverse requirements
3. Continuous evolution and deployment
4. Heterogeneous, inconsistent, and changing elements
5. Erosion of the people/system boundary



Today's Approaches

The Engineering Perspective - for large scale software-intensive systems

- largely top-down and plan-driven
- requirements/design/build cycle with standard well-defined processes
- centrally controlled implementation and deployment
- inherent validation and verification

The Agile Perspective - proven for smaller software projects

- fast cycle/frequent delivery/test driven
- simple designs embracing future change and refactoring
- small teams and retrospective to enable team learning
- tacit knowledge

Today's approaches are based on perspectives that fundamentally do not cope with the new characteristics arising from ultra-large scale.

The mentality of looking backward doesn't scale.



A New Perspective is Required

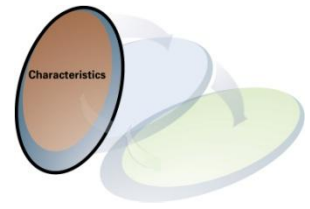
“The older is not always a reliable model for the newer, the smaller for the larger, or the simpler for the more complex...Making something greater than any existing thing necessarily involves going beyond experience.”

Henry Petroski

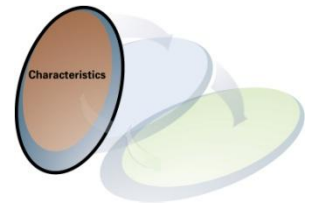
Pushing the Limits: New Adventures in Engineering



Today We Build “Buildings”



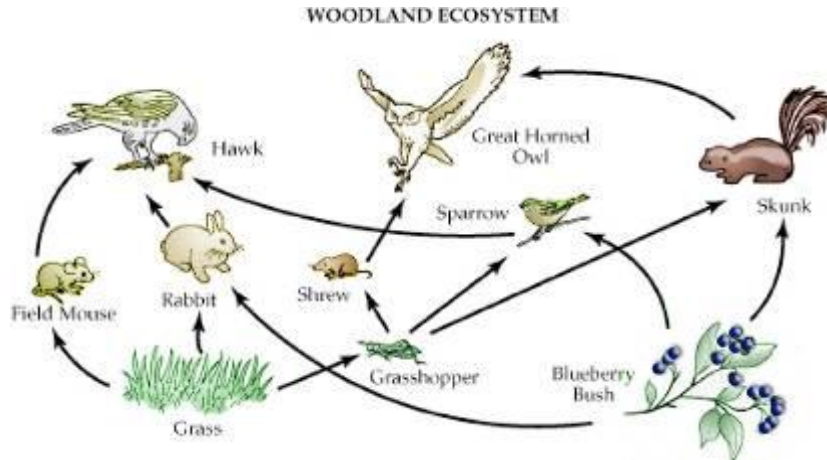
We Need To Think Cities



“Cities are places of massive information flows, networks, and conduits, and myriad transitory information exchanges.”
Howard Rheingold: *Smart Mobs*



We Need to Think Ecosystem



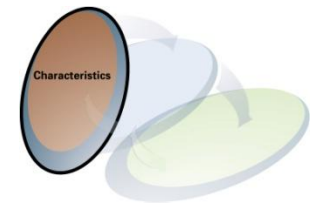
Diverse users with complex networked dependencies and intrinsic adaptive behavior

Has:

- Robustness mechanisms: achieving stability in the presence of disruption
- Measures of health: diversity, population trends, other key indicators

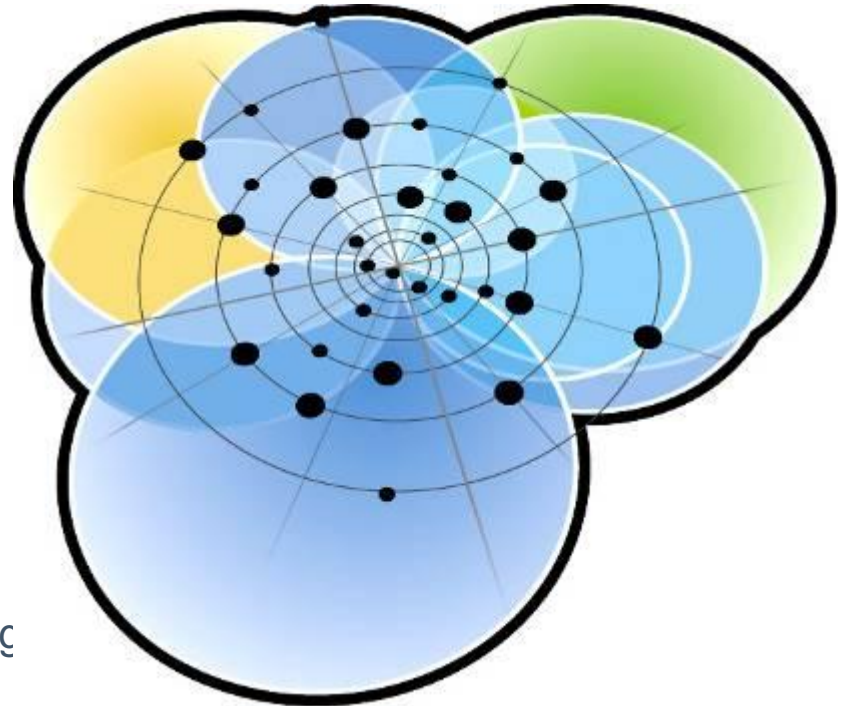


We Need to Think Socio-Technical Ecosystems

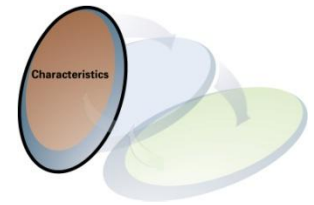


Socio-technical ecosystems include people, organizations, and technologies at all levels with significant and often competing interdependencies.

- There will be competition for resources.
- There will be organizations and participants responsible for setting policies.
- There will be organizations and participants responsible for producing ULS systems.
- There will need to be local and global indicators of health that will trigger necessary changes in policies and in element and system behavior.



Why a New Perspective?



There are fundamental assumptions that underlie today's software engineering and software development approaches that are ***undermined*** by the characteristics of ULS systems.

There are challenges associated with ULS systems that today's perspectives are very unlikely to be able to address.

In ULS systems, we now are dealing with not just software but an ecosystem of people, organizations, governance, social interaction, hardware, and software.



Challenges

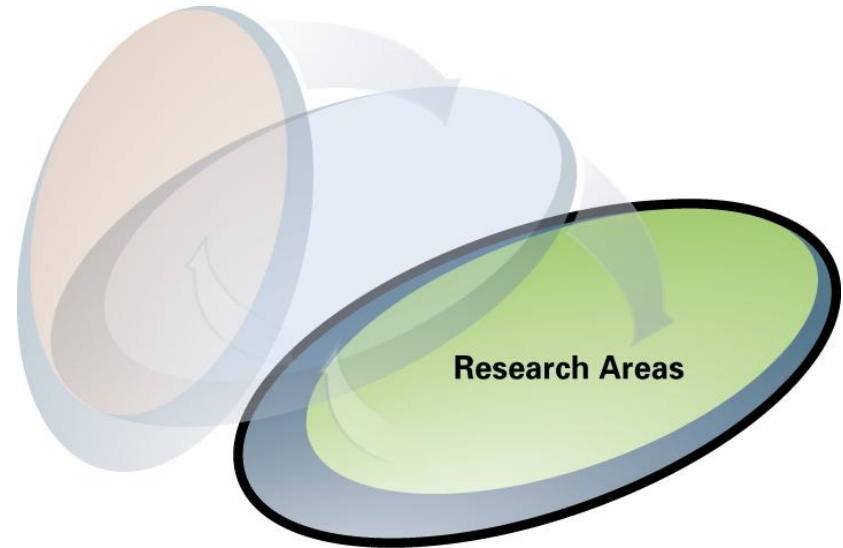
ULS systems will present challenges in three broad areas:

- Design and evolution
- Orchestration and control
- Monitoring and assessment



Where Do We Focus Our Research

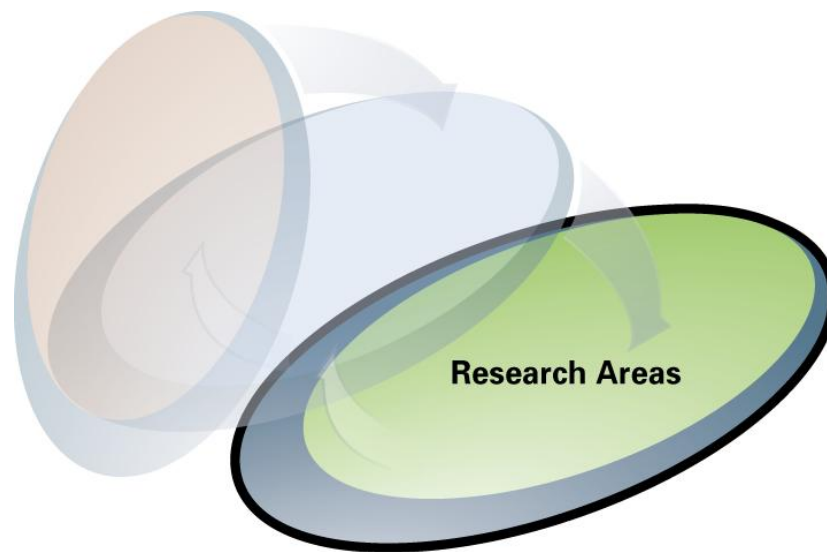
- Address the predominant characteristics of ULS systems and the three challenge categories.
- Look for breakthroughs not incremental improvement in current approaches.
- Take a more expansive view of software research and include its interactions with associated research in the physical and social sciences.



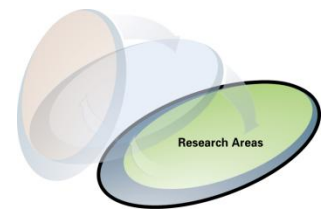
Research Portfolio

We recommend an interdisciplinary portfolio of seven research areas and suggested topics for breakthrough research needed to meet the challenges associated with ULS systems.

- Is not expressed in terms of today's "hot" technologies.
- Does not supplant current software research.
- Expands today's horizons.



Research Areas - 1



6.1* Human Interaction: involves anthropologists, sociologists, and social scientists conducting detailed socio-technical analyses of user interactions in the field, with the goal of understanding how to construct and evolve such socio-technical systems effectively.

6.2 Computational Emergence: explores the use of methods and tools based on economics and **game theory** (e.g., **mechanism design**) to ensure globally optimal ULS system behavior by exploiting the strategic self interests of the system's constituencies; explores **metaheuristics** and **digital evolution** to augment the cognitive limits of human designers.

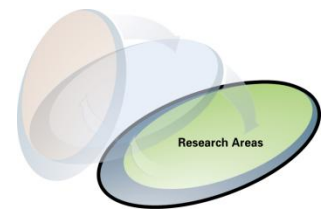
6.3 Design: broadens the traditional technology-centric definition of design to include people and organizations; social, cognitive, and economic considerations; and design structures such as **design rules** and government policies.

6.4 Computational Engineering: focuses on evolving the expressiveness of representations to accommodate the semantic diversity of many languages and focuses on providing automated support for computing the evolving behavior of components and their compositions.

* Section in report where research area is described



Research Areas - 2



- **6.5 Adaptive System Infrastructure:** investigates integrated development environments and runtime platforms that will support the decentralized, “always-on,” nature of ULS systems as well as technologies, methods, and theories that will enable ULS systems to be developed in their deployment environments.
- **6.6 Adaptable and Predictable System Quality:** focuses on how to maintain quality in a ULS system in the face of continuous change, ongoing failures, and attacks and how to identify, predict, and control new indicators of **system health** (akin to the U.S. gross domestic product) that are needed because of the scale of ULS systems.
- **6.7 Policy, Acquisition, and Management:** focuses on transforming acquisition policies and processes to accommodate the rapid and continuous evolution of ULS systems by treating suppliers and supply chains as intrinsic and essential components of a ULS system.



What We Learned That We Want to Share

There is an unstoppable trend toward increasing scale in many systems important to our society.

Scale changes everything.

Manifestations of scale and its attendant complexity arise in many disciplines, and can be understood as a phenomenon in its own right.

New, interdisciplinary perspective and new research in building ultra-large-scale systems is long overdue.

“Since computation has moved over the past twenty years decisively closer to people, interfaces with social sciences such as Psychology and Sociology, besides Economics, have become increasingly important”

Christos H. Papadimitriou, in “Algorithms, Games, and the Internet”



ULS Systems Research Study Report

Acknowledgements

Executive Summary

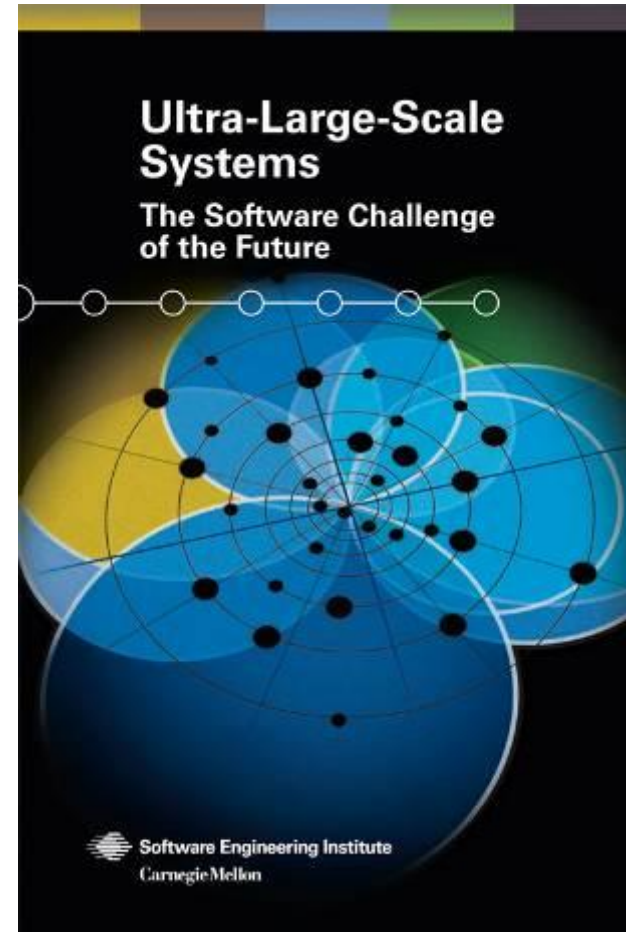
Part I

1. Introduction
2. Characteristics of ULS Systems
3. Challenges
4. Overview of Research Areas
5. Summary and Recommendations

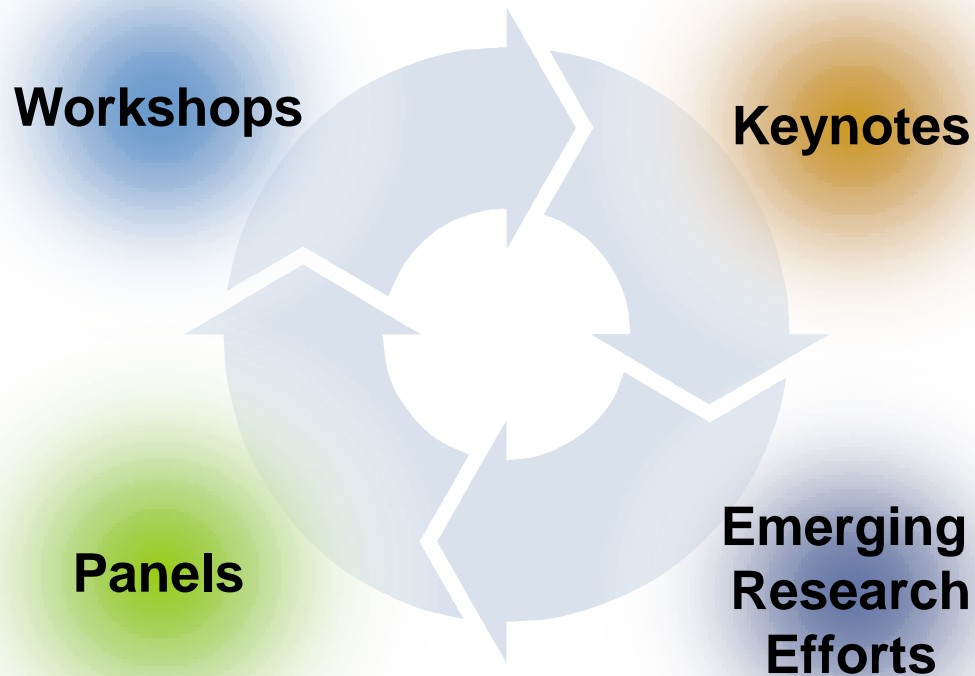
Part 2

- 6 Detailed Description of Research Areas
- Glossary

<http://www.sei.cmu.edu/uls/>



The Start of a Collaborative Research Network

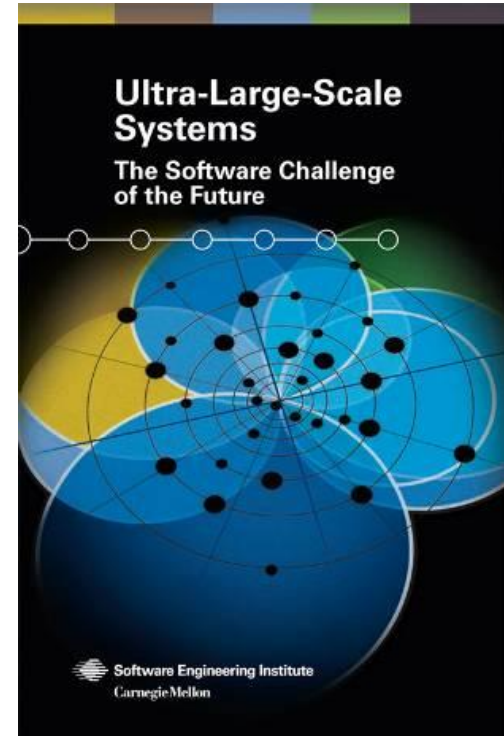


Activity Since Report Published in May 06

There is growing community interest and research starts.

Since July 06

- more than 120,000 downloads of the report
- more than 3,900 copies of the report distributed
- more than 25 keynotes and more than 60 presentations by author team
- five press and one industry analyst interviews
- feature story on ULS systems in the May/June issue of IEEE Software
- research workshops at OOPSLA 2006, ICSE 2007, and ICSE 2008
- SMART ULS System Forum (March 2008)
- National Science Foundation center established
- Roadmap Exercise funded by Army organization (CERDEC)



<http://www.sei.cmu.edu/uls>



Post-Study Observations

The study does not contend that all systems of the future will be ULS systems. Clearly, they won't be.

Many believe that there are ULS systems today.

What you call a system (system of systems, ULS system, complex net-centric system) is really unimportant.

It is important that ULS system characteristics are recognized.

- These characteristics undermine the assumptions we make in most current technical, management, and acquisition approaches.
- The ULS system perspective is helpful in understanding some of the current technology and management shortcomings and issues with system of systems.

The research identified in the ULS system study can also have a positive impact on systems that are not ULS.



SEI Work on ULS Systems

Research:

- Computational Mechanism Design
- Architecture in ULS system context
- Edge Programming
- Distributed governance in dynamic contexts
- Assurance in ULS systems

Transition and Community Building:

- Website
- Technical Workshops
- Continued publications
- Continued presentations and keynotes
- Non-DoD ULS system book that includes essays



Summing It Up

The characteristics of ULS systems undermine assumptions of traditional software and systems engineering practice.

Approaches to meeting the challenges of ULS systems can be found in, or at least inspired by, other disciplines, such as biology and economics.

Many of today's challenges are harbingers of future ULS system challenges, and today's systems can benefit from taking a "ULS system perspective."



Contact Information

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A group of business professionals in a networking event. A man in a light grey suit and red tie is handing a business card to a woman in a dark blue blazer. Other people in business attire are visible in the background, some holding cards and talking.

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